Sharklet Brings New Technology to Electroimpact E4000 LVER Machine

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Carter L. Boad and Paul Haworth
Electroimpact Inc.

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ABSTRACT

Electroimpact's E4000 LVER riveting machine entered service in 1998 assembling A320/A321 upper wing panels at the Airbus wing manufacturing facility in Broughton, Wales. Airbus's recent introduction of the Sharklet modification to the wings of the A320 family of aircraft necessitated a number of changes to the machine and fixture to accommodate the revised wing geometry. Electroimpact and Airbus also worked together to identify a wide range of machine improvements and updates. A short list of the changes made to the machine includes a new CNC, new motors, scales, spindles, and new technologies such as laser tracers and normality sensors. The end result is a faster, more accurate machine with state-of-the-art controls ready to support Airbus's A320/321 wing panel assembly for the next 15 years.

INTRODUCTION

Electroimpact introduced its E4000 LVER (Low Voltage Electromagnetic Riveter) machine to Airbus's wing factory in Broughton, Wales in 1998. The machine and two fixtures were designed to manufacture A320 and A321 upper wing panels. The machine, known in the factory as SA1 (Single Aisle 1) successfully produced wing panels for 5 years before being joined by another Electroimpact LVER machine, the HSRM (High Speed Riveting Machine), which was capable of riveting pre-tacked A320/321 panels as well as A300, A330, and A340 panels. Then in 2006 Airbus commissioned SA2 (Single Aisle 2), another Electroimpact LVER machine, similar to SA1 but featuring current technology and a state of the art controller.

Airbus recently introduced a major update to the A320/321 wing called Sharklet. It is a modification whereby a vertical fin is added to the end of the wings to gain efficiency. This modification required considerable re-engineering of the wings, changing both the skin and stringer thicknesses and profiles over the majority of the panel assemblies. These design changes necessitated alterations to all the machines and fixtures that would be used to manufacture the new wings.

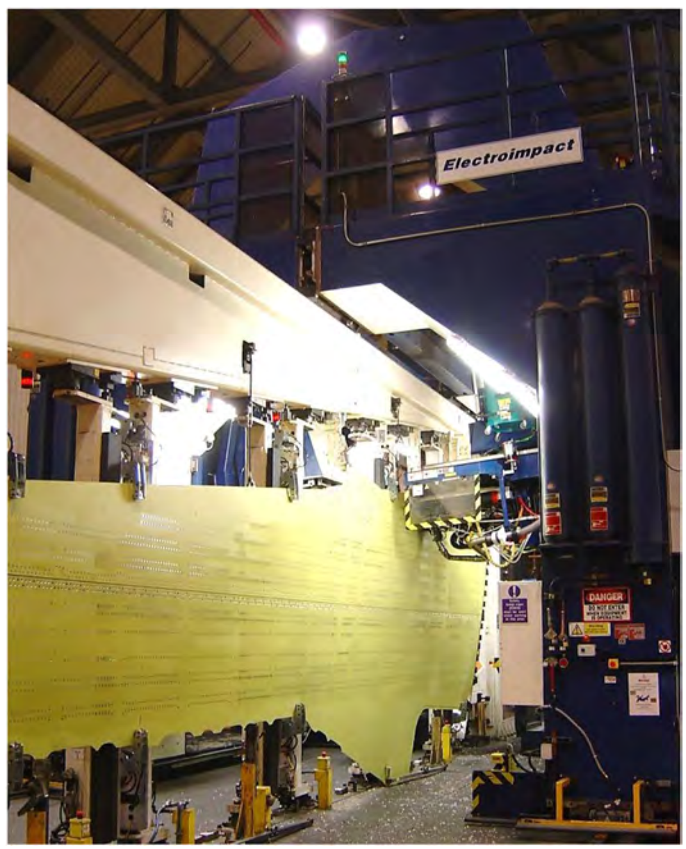

Figure 1. E4000 (SA1) machine working on an A321S panel

Although the HSRM and SA2 machine cells would be modified to accommodate the new wings, Airbus saw this as an opportunity to not only modify the SA1 machine for Sharklet, but to upgrade the aging machine so it could continue to produce wing panels for the next 15 years. The modifications were extensive and included a new CNC, new motors, scales, and spindles as well as new technologies such as laser tracers and normality sensors. After the modifications were complete, the SA1 machine re-entered production effectively as a new machine, but without the slow ramp-up, schedule risks, and teething problems of a brand new machine (see Figure 1).

TECHNICAL DESCRIPTION OF THE RETROFIT

Challenges Presented by the Retrofit

Although the SA1 machine has had some of its hardware upgraded or replaced over the years, it was still a 14 year old machine running on a 14 year old CNC. Some of the spare parts for the machine had become no longer available (NLA) and some of the hardware and subsystems had grown obsolete. This began to pose a significant production risk as the potential down-time in the manufacturing cell while a difficult to find or obsolete spare part was sourced or re-designed would be difficult to absorb.

In addition, some of the systems had become technologically out-dated and slow by today's standards - effectively hamstringing the machine when comparing it to brand new manufacturing systems being offered by Electroimpact and others in the industry.

Planned Improvements

The SA1 manufacturing cell was one of the plant's most productive, even with the problems listed above. The machine and two fixtures produced approximately eight ship-sets/month and had drilled over ten million holes since it was first put into service. To completely replace the machine with a new one would carry considerable expense in both capitol and lost production time. Airbus recognized the value of a potential full-scale refurbishment and contacted Electroimpact to develop a plan and request a quote for the work.

Airbus and Electroimpact both came to the table with a list of requests and requirements and worked together to outline the scope of the project. Airbus's list contained the all the accommodations necessary to produce the new wing panels along with a new machine specification outlining the performance requirements the refurbished machine would have to meet, while emphasizing minimum machine down-time during the retrofit. Electroimpact's list contained the minimum necessary hardware changes to produce the Sharklet panels along with a long list of recommended improvements to the machine to bring it up to 2012 standards. In addition, we requested historical data from the maintenance team to highlight the top ten sources of machine down-time over the previous six months. We then offered solutions to these ongoing problems as part of our work package.

Control System/Electrical Improvements

The E4000 (SA1) machine used a Fanuc 15-MB CNC control which was all but obsolete. Not only was it becoming difficult to find spare/maintenance parts, it was one of the top sources of machine down-time. It was also a constant factor in machine down-time in general as fault finding was very tedious due to the antiquated HMI. The limited ladder space on the old control required three satellite PLC's to run the EMR controls, the fastener feed system and the FAJ. Electroimpact chose the Fanuc 30i CNC to replace the old controls and PLC's, allowing the machine to take advantage of the latest hardware and software from Fanuc.

General wear and tear, maintenance, and previous retrofits had taken their toll on the machines wiring and electrical sub-systems, contributing to another major source of down-time. Completely replacing all the machine's existing wiring would eliminate all of those problems and would also, perhaps counter-intuitively, reduce the installation time to a minimum. We would completely build new controls and I/O cabinets at Electroimpact and ship them ready to mount and terminate. Most of the cables were connectorized and documented prior to delivery as well in order to reduce time taken to terminate cables on-site.

Improved Servo Axis Control

Since the installation of the E4000 machine in 1998 there have been significant advancements in servo control performance. The original SA1 machine was delivered with a FANUC 15 model B controller and Alpha series servo motors. The new SA1 CNC, a FANUC 30i model A uses FANUC Alpha-iS and Alpha-iF series servo motors controlled with a high speed servo system that offers twice the current loop response rate that was available on the 15 series controller. The High-Response Vector software version 2 (HRV2) available on the 30i CNC offers a current loop response time of 125µs (which is half of the 250µs capability of HRV1 offered on the 15 series.) This improvement in servo control performance, coupled with enhancements to system/motor inertia ratios was a key factor in attaining a 20% reduction in process cycle time.

Enhancements to HMI

In addition to enhancements in servo control, the newer 30i control also offered opportunities to greatly improve the size, clarity and functionality of the machine HMI. The older control used a 10″ CRT display running a text based HMI. The new control uses a 15″ LCD touch screen display running a full colour text/graphical user interface. The original 15 series based HMI can be seen in Figure 2, and the updated interface in Figure 3.

Figure 2. 15-M based operator interface

Figure 3. 30i based operator interface

Using the FANUC custom HMI designer, Fanuc Picture, Electroimpact was able to offer a custom machine interface that dramatically improved the end user experience. A new suite of maintenance screens added to the HMI have also helped to reduce MTTR by improving the quality of maintenance information available to technicians that attend machine breakdowns.

By taking advantage of the graphical user interface features of Fanuc Picture, a significant reduction in the size and complexity of the hard-button panel was achieved. Custom soft-button layouts which adapt according to the current machine mode greatly enhance the ease of use of the machine and reduce the likelihood of downtime caused by operator error. Figure 4 shows an example of the custom screens developed for the SA1 refurbishment project. This example highlights the level of detail and clarity that has been incorporated into the software HMI.

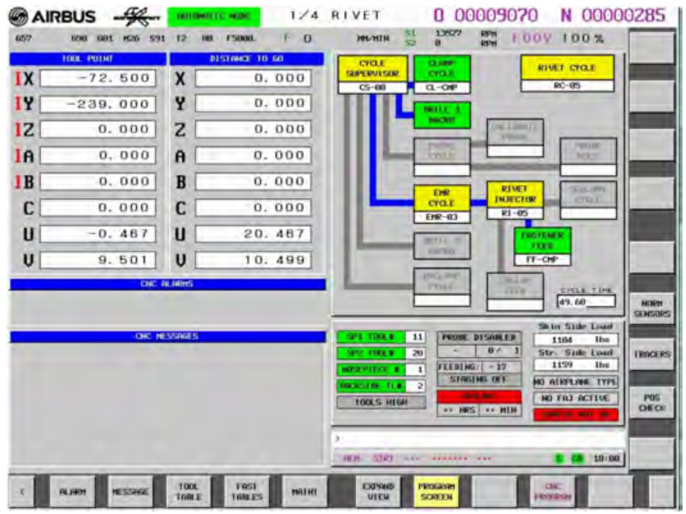

Figure 4. 30i based custom HMI example screen

Smarter Cycle Architecture

The Fanuc 30i controller offered an opportunity to optimise the software that controls the machine process cycles using Multipath-Control. Older CNC systems are only capable of processing a single set of NC programming instructions. For a complex multi axis machine such as E4000 this presented a significant programming challenge in cases where 5-axis major machine motion and single axis process tool motion are required to happen simultaneously and asynchronously. An example of this would be advancing the drilling servo axis to a standby position during the machine pitch move from a completed fastener to the next hole location, which is desired to reduce cycle time.

Achieving this kind of machine motion on the older 15 series controller using NC commands is very hard to achieve. It is typical to use the PMC to control the motion of the tool axis, which resulted in a disconnect between the NC code handling the major axis motion and the PMC software handling the motion of the tool axes.

By utilising the Multipath-Control feature of the FANUC 30i CNC the new SA1 software controls both major 5-axis motion and process tool axis motion using NC statements running asynchronously across 2 CNC paths. This approach created a software architecture that was not only more efficient but more transparent and configurable for the end user. Improvements in cycle efficiency also contributed to the 20% cycle rate improvement.

Transition to Integrated Control

Capacity and functionality limitations of the 15 series controller forced Electroimpact to utilize a number of satellite PLC systems (GE 90-30) when the control architecture was originally developed. During the recent refurbishment, there was an opportunity to remove all of the PLC's from the machine and absorb the PLC's into the PMC embedded within the 30i CNC system. The PMC is a single logic based software system that duplicates and enhances the functionality previously carried out by PLC's. This results in a dramatic reduction in overall complexity of the control system, reduces the number of separate software programs required and eliminates maintenance problems commonly associated with distributed control systems.

Mechanical Improvements

Most of the mechanical changes and improvements were found in the stringer side tooling, drill/shave spindles, headstone, motors, scales, and a new operator station. The stringer side tooling (anvils) used for riveting had to be redesigned to access fasteners under the revised stringers. Electroimpact took this opportunity to make the new SA1 and SA2 tooling identical so that they could be used on either machine which reduces spares holdings, maintenance training and other benefits associated with common tooling. The most significant change to the tools however was the use of lasers in place of the old mechanical tracer assemblies.

Figure 5. Laser tracer assemblies

Tracers contact the wing while the machine is moving, measuring the distance between the machine and the part. By their nature, mechanical sensors are susceptible to crashes with parts and fasteners. These crashes lead to machine down-time. Electroimpact evaluated a number of non-contact laser sensor candidates and settled on Baumer OADM12I6460/S35A laser distance measuring sensors. These have an accuracy tolerance of +/−1.3 mm over a range of 40 mm enabling us to meet the positional and rotational accuracies in the machine specification without touching the part. Figure 5 shows the stringer side rivet tooling with Baumer laser Y (foreground) and V (background) laser tracers.

Although the legacy SA1 spindles had been very reliable, they were custom Electroimpact spindles that were more difficult to maintain than the off-the-shelf cartridge type spindles used on our new machines. The legacy spindles were also limited to 12,000 RPM and were controlled with older third party digital spindle drives (MCS DA series) which had suffered considerable reliability problems. New spindle assemblies were designed with an Electroimpact drive system built around standard HSK-E50 Fischer spindles (MFW-1412). These new water cooled spindles are capable of 20,000 rpm and are both more efficient and temperature stable than the spindles they replaced, which improves countersink and shave repeatability (spec requirement +/− 0.025mm). The new spindles are also controlled with Fanuc spindle drives (SPM-30i) which give much improved fault diagnosis capability when compared to the MCS drives they replaced.

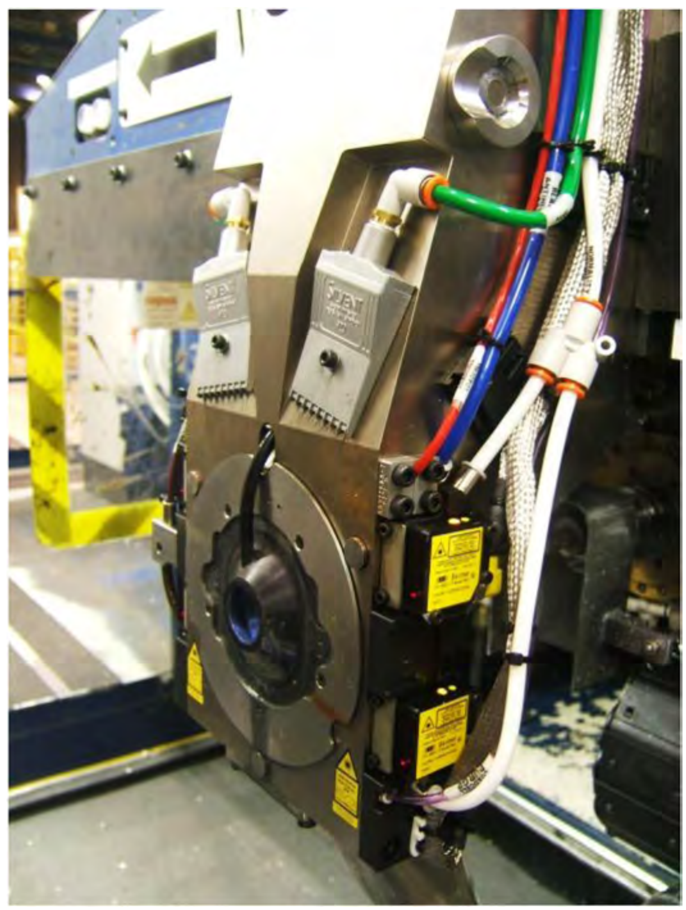

Figure 6. Headstone with laser normality sensors

In addition to the new spindles, the skin side of the machine was further upgraded with a new headstone assembly. This new assembly featured an integrated load cell, laser normality sensors, and a revised process camera. The legacy machine measured clamp force using a load cell attached to the ball-screw assembly. By moving the loadcell to the headstone, just behind the clamp pad, the accuracy and response time was greatly improved. We expected a clamp cycle time reduction of at least 100ms through the use of this new loadcell. Figure 6 shows the new headstone assembly.

Like the mechanical tracers on the stringer side tools, the old headstone used mechanical normality sensors on the skin side. Although functionally sound, they were one of the top five causes of breakdowns on the machine, mostly due to the sensors being constantly knocked off the headstone or damaged as they were accidentally and repeatedly run into holes, dowels, slave bolts, fixture clamps, etc. The same Baumer OADM12I6460/S35A laser sensors were chosen to replace the old normality sensors. These compact sensors could be permanently mounted to the side of the headstone and their low profile meant better protection from potential damage.

The old headstone had an integrated camera that provided a view of the process but it was not very effective and was difficult to set up and keep working properly. The new camera was based on the SA2 design and repositioned lower in the headstone to provide the operator a much better view of the drilling and riveting process. The new camera is also easier to set-up and requires minimal maintenance.

Along with the drives, all the servo motors on the machine were preplaced with the latest Fanuc offerings (Alpha *i* series). Many of the new servo motors are able to spin up to 6000 rpm vs. the 3000 rpm limit on the old motors. This increase in available speed resulted, in some cases, in better axis performance contributing to the reduced cycle times we achieved. In addition to new motors, most axes received the latest Heidenhain LC493F linear absolute scales. These scales are absolute vs. the incremental scales they replace and they are also currently available products, which was not the case with some of the older scales on the machine. On the Y axis we installed LC139F scales because the travel exceeds the longest LC439F. These scales have the same benefits but a different package. Finally, on the X-axis, we installed Renishaw LM10 distance coded tape scales. The LM10 magnetic scale replaces an older, less robust Renishaw RG2 optical scale.

The last major mechanical upgrade we offered was a new operator station. The machine was originally delivered with the operator controls on the skin side of the machine. The controls were later moved to the stringer side when it was determined that it was advantageous to give the operator a better view and access to the stringer/anvil interactions. Neither configuration offered much in the way of ergonomics or comfort, so we offered to remove the old stringer side operator platform and replace it with a new larger platform. During the design review process, Electroimpact presented Airbus with layout options which they took to their operators to get their comments and buy-in. This turned out to be a very nice finishing touch to the mechanical system improvements and the operators were very pleased with the results, which can be seen in Figure 7 and Figure 8.

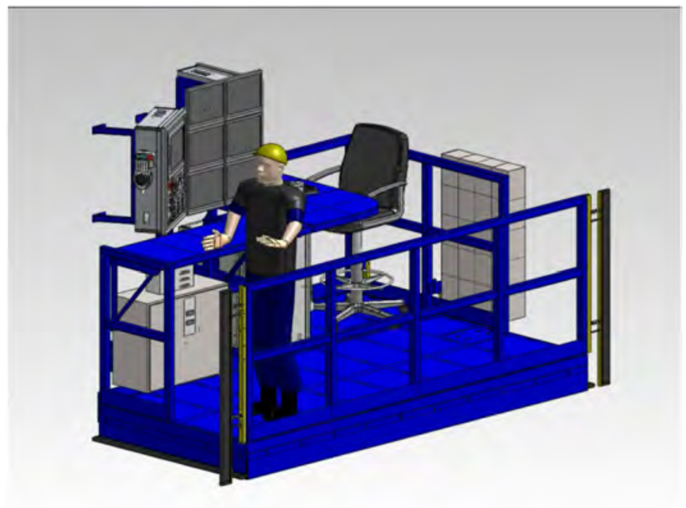

Figure 7. ISO view of new operator station

Figure 8. New operator station

Solution Implementation

Contract Overview

The initial specification for the work was released in October, 2010 with the request for quote (RFQ) due in January, 2011. Airbus issued Electroimpact a purchase order for the work in March, 2011 after a number of spec and contract reviews. Design reviews were conducted in the months following, coming to a final conclusion in June, 2011. The work was now fully defined for all three machines being updated. HSRM would be first in August, 2011, followed by the SA1 machine in October, and finally the SA2 machine in June, 2012.

Planning

In an effort to reduce the retrofit workload, electrical engineers from Electroimpact visited the SA1 machine six months prior to the scheduled start date. They collected information on the current state of the machine, cable run distances, and looked for opportunities to reuse existing wiring. Using the data gathered during the reconnaissance visits they designed, assembled, and prewired each electrical enclosure from the main drives cabinet to the smallest limit switch junction box before being packed for shipping to the Airbus site. The preparatory trips allowed for the shifting of work from the customer's site to our own, where it could be completed more efficiently and quickly.

Also during this time, Electroimpact worked with Airbus to conduct a “machine survey” to measure and document the existing performance of the machine. This work served as a baseline with which we could measure process improvements against. It also helped both parties better understand the current performance of the subsystems which would not be retrofitted so there were no undoexpectations during the FAT process. The cycle performance data from the machine survey is included in the appendix.

All the new mechanical subsystems were assembled and tested at Electroimpact during this time as well. The new hardware, electrical cabinets, cables, and installation tools were gathered together and loaded into a 20′ container which left the shipping dock on September 2nd, 2011.

To help Electroimpact and Airbus maintain schedule visibility, daily “morning meetings” would be held with representatives from Airbus and Electroimpact, lead by our CDM (Construction Design and Management) coordinator. These meetings served to highlight progress, identify schedule risks, address any safety concerns, and generally keep both parties on the same page through the duration of the refurbishment process.

Strip Down

The SA1 machine was released from production on October 13th, 2011. A team of six to eight engineers and technicians quickly stripped the machine of all the old electrical cabinets, cables, motors, gearboxes, and other mechanical systems that would not be re-used. Scaffolding was erected around the machine during this process to allow safe work access. In addition, the Electroimpact UK maintenance engineers removed all the process tools for cleaning, evaluation, and repairs in order to help eliminate any downtime due to existing hardware that would be un-changed during the refurbishment. Airbus maintenance assisted as well, helping us to clear the foundation of scrap and re-claim useful components from the systems that were removed. These activities were finished before the end of the month.

Rebuild

Over the next five weeks, the machine was re-assembled with all the new hardware and electrical cabinets. Electrical/wiring activities accounted for the bulk of this work. To reduce the amount of time needed for cabling and wiring of the machine we carefully managed and streamlined the electrical installation. Modern drives and the addition of a Profibus network for distributed I/O allowed for a significant reduction in the number of cables required. Common routes between cables were identified and combined into larger multi-core cables. Spare conductors were also added between each enclosure and the main I/O cabinet. In addition to allowing for future expansion, these spare conductors allowed for quick re-routing of signals and helped streamline the debug phase. Each of these steps reduced the time required by the electrical engineers to complete their work before handing the machine over the to the control engineers. Through much hard work and long hours, we achieved power-up on December 6th, 2012, a full day ahead of schedule.

Debug

The most time consuming part of the project is debugging the all of the hardware, electronics, and machine processes. This portion of the project was broken up in the 3 main parts; initial control system debug, machine process setup, and machine process debug. Four controls engineers with support from various mechanical and electrical engineers worked shifts around the clock to maximize effectiveness. The initial control system debug involved debugging all the I/O, pneumatics and servo axis. This ran through mid January 2012. The machine process setup involved setting hard and soft limits, aligning the axes, calibrating, sensors, setting up fastener feed, etc. These efforts were largely completed by the first week in February, 2012. Finally, the machine processes were debugged and axes compensation was completed. Then all portions of the machine cycles were tested and debugged before making test coupons, and then finally, installing fasteners in a curved test panel to replicate an actual wing. We also ran through FAT (Final Acceptance

Test) items prior to ensure the machine performance was acceptable. The machine was ready for FAT by the middle of March, 2012, right on schedule.

Solution Verification

FAT

Airbus produced a list of FAT items to test and evaluate the updated machine. The tests included accuracy, repeatability and rate tests for all axes, machine functionality tests, machine configuration checks, and various other specification items. The tests were performed by Electroimpact controls engineers working in the presence of Airbus manufacturing engineering representatives. The performance of the machine axes were verified by both laser metrology and hand-held inspection tools. Functionality tests were demonstrated by running machine cycles, evoking auto-recovery scenarios, and other basic machine feature demonstrations. The machine configuration and remaining spec items were simply checked against a list. FAT was mostly completed in just a few days. As soon as the FAT items associated with the drilling and fastening process were passed, Airbus was able to start re-cert activities on night shift which gave us a head start on the schedule. The short FAT period was achieved by a detailed series of pre-testing completed in the debug/testing portion of the project. This reduced, and virtually eliminated, cases of test failures or non-conformances which was a critical step in ensuring compliance to the schedule.

Recertification

The last requirement necessary before turning the machine over to production was to ensure that holes drilled and fasteners installed by the machine met the production standards and specifications. Airbus's manufacturing engineering teams were responsible for certifying the machines for production. Certification involved producing coupons for all fastener/stack combinations and then cutting out the fasteners to check for expansion, hole-fill, etc. EMR voltage settings were adjusted between each run of coupons until all settings were finalized. Two teams worked in parallel during this process, one for classic panels and one for the new Sharklet panels. Electroimpact controls engineers were present to support the effort and continued to make adjustments/improvements to the machine process code and debug problems if they arose. The machine was pronounced ready for production during the first week of April, 2012, less than six months after it was removed from production.

Production

Instead of a gradual re-entry into production, Airbus required a considerably more aggressive ramp up back to the full production rate of a panel every 3.5 days. After a short period of panel ink marking (CADO) to confirm the accuracy of the fixture and the machine, a comprehensive TTO (Tape Try Out) period commenced.

During the TTO process the machine performance was closely monitored, and during this process the machine performance did not fall below 94% (the contracted uptime guarantee). EI provided close support to Airbus engineers to enable them to take full advantage of the new features of the machine.

Production Support

Electroimpact has recognized over a series of past projects that close dedicated support for new (or newly refurbished) machines is key to achieving high production rates, especially on programs where the required machine productivity is very high. A key goal of the software development process on this machine was to reduce the maintenance burden, and this has been achieved through a series of improvements and simplifications. However throughout the TTO process, and for the first 6 months of production EI has also provided dedicated software support to further guarantee the success of the refurbishment.

SUMMARY/CONCLUSIONS

Electroimpact's SA1 machine is now ready for the next 15 years. The machine was removed from service for only six months for the entire retrofit process and was immediately able to re-enter production at a much higher rate than a brand new machine, and at a fraction of the cost. The success of this project was made possible by possible by a number of factors. Electroimpact and Airbus maintained a very close working relationship through the entire process. Together we built a list of engineering solutions to accommodate the new Sharklet wings, address historical maintenance issues, and generally upgrade the machine. The project was carefully managed to ensure minimum machine down-time and minimum risk. And the project team was assembled with some of our best and most dedicated engineers and technicians, who all worked efficiently and tirelessly to meet the schedule. Airbus now has an updated manufacturing cell capable of producing A320 and A321 classic and Sharklet panels with a 20% increase in cycle rate capability (see Appendix for details) and reduced maintenance downtime.

REFERENCES

Zieve, P. and Smith, A., “Wing Assembly System for British Aerospace Airbus for the A320,” SAE Technical Paper 982151, 1998, doi:10.4271/982151.

Holden, R., Haworth, P., Kendrick, I., and Smith, A., “Automated Riveting Cell for A320 Wing Panels with Improved Throughput and Reliability (SA2),” SAE Technical Paper 2007-01-3915, 2007, doi:10.4271/2007-01-3915.

CONTACT INFORMATION

Carter Boad is a Mechanical Engineer and Project Manager, and Paul Haworth is a Controls Engineering Manager at Electroimpact Inc.

Carter Boad, Electroimpact, Inc.
carterb@electroimpact.com

Paul Haworth, Electroimpact, Inc.
paulh@electroimpact.com

Chris Wright is an Automation Engineer at Airbus in the UK.

Chris Wright, Airbus in the UK
christopher.d.wright@airbus.com

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DEFINITIONS/ABBREVIATIONS

SA1 - Single Aisle Machine #1

SA2 - Single Aisle Machine #2

HSRM - High Speed Riveting Machine

EMR - Electromagnetic Riveter

CNC - Computer Numeric Control

15-MB - 15 Series Model B Control

30i-MA - 30i Series Model A Control

HRV - High Response Vector

FAJ - Floor Assembly Jig

MTTR - Mean time to repair

I/O - Inputs & Outputs

PLC - Programmable Logic Controller

PMC - Programmable Machine Controller

CDM - Construction Design and Management

FAT - Final Acceptance Test

TTO - Tape Try Out

APPENDIX

Riveting

SA1 Survey
Date 7/28/2011

Variables	
Feed Rate	5000
Stack	16.25
Rdecode	On
Tools Low	On
Probing	Off
Pitch	1"

No. of Rivets	42	42	42	42
Minutes	7	7	8	8
Seconds	53	58	18	23
Fasteners per min	**5.33**	**5.27**	**5.06**	**5.01**

Average **5.17**

SA1 FAT
Date 3/20/2012

Variables	
Feed Rate	5000
Stack	16.25
Rdecode	On
Tools Low	On
Probing	Off
Pitch	1"

No. of Rivets	44	44	44	31
Minutes	7	7	7	4
Seconds	24	13	7	58
Fasteners per min	**5.95**	**6.10**	**6.18**	**6.24**

Average **6.12**
Improvement +18%

Bolting

SA1 Survey
Date 7/28/2011

Variables	
Feed Rate	5000
Stack	16.25
Rdecode	On
Tools Low	On
Probing	Off
Pitch	1"
Sealant	On

No. of Bolts	42	42	42	42
Minutes	10	10	10	9
Seconds	40	24	35	32
Fasteners per min	**3.94**	**4.04**	**3.97**	**4.41**

Average **4.09**

SA1 FAT
Date 3/20/2012

Variables	
Feed Rate	5000
Stack	16.25
Rdecode	On
Tools Low	On
Probing	Off
Pitch	1"
Sealant	On

No. of Bolts	37	44	42	40
Minutes	7	9	8	8
Seconds	7	31	16	2
Fasteners per min	**5.20**	**4.62**	**5.08**	**4.98**

Average **4.97**
Improvement +22%

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

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